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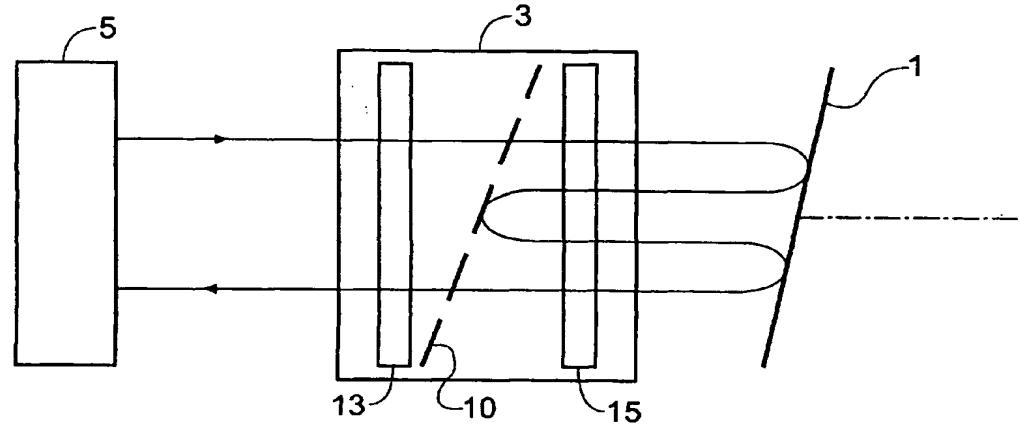
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(54) Title: SCANNING APPARATUS



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(57) Abstract: A scanning apparatus comprises two rotatable bodies (1, 10 or 40) arranged to rotate in opposite directions. The first body being a polariser (10) and the second being a mirror (1) or a second polariser (40). The apparatus is arranged to define an optical path for a polarised beam, wherein the optical path passes through the first body (10), is reflected at the second body (1 or 40), and is reflected by the first body (10) back to the second body (1 or 40) from where it is transmitted or reflected to produce a linear scan. There is also disclosed a scanning system comprising a reflector (1) and an optical wedge (42) containing refractive materials, arranged to counter rotate and arranged so that a beam passing through the optical wedge (42), is reflected by the reflector (1) and passes back through the optical wedge (42) to produce a linear scan.

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SCANNING APPARATUSBackground of the InventionField of the Invention

The present invention relates to a scanning apparatus which may be used in a real-time imaging system, and in particular in a real-time mm wave length, or microwave imaging system.

Summary of the Prior Art

In optics, there is a requirement to scan beams rapidly across the scene in a linear scan pattern.

For visible light, it is known to achieve a linear scan pattern by the use of two circular rotating reflective discs, which are equally inclined to their axes of rotation, and which rotate at the same speed. A single rotating mirror would produce a conical scan. However, when the second rotating mirror receives a conical scan from the first rotating mirror parts of the conical scan are effectively cancelled out resulting in a linear scan pattern. Alternatively flapping mirrors may be used to achieve a linear scan pattern.

Such methods are suitable in the visible region where the apertures involved are small. In the infra-red region apertures are frequently about 100 mm and focussing lenses are used to reduce this aperture to around 10 mm. In the mm-wave and microwave regions these

apertures are very large (in the order of 1 m) and it is not practical to use flapping mirrors. Also when making reflective discs, there is considerable displacement of the beam which is received by the second of the mirrors,
5 and therefore the second mirror has to be very large so as to be able to receive the displaced beam.

It is also known, for visible light, to produce a linear scan using two counter rotating prisms. However, such prisms are heavy and therefore not suitable for
10 large aperture systems.

Summary of the Invention

The present invention aims to provide a system for producing linear scans which is of suitable size and weight to be used in mm wave length and microwave
15 applications. In other words the invention aims to provide a system which performs the function of the flapping mirrors, in effectively converting conical to linear scans.

In general terms, the invention uses at least one
20 rotating polariser which, depending on the point in the optical path of the beam transmits and reflects the beam, so that the beam can pass through the polariser but then be reflected from another body back to the polariser to be reflected therefrom to cause cancellation of conical

scans to produce a linear scan by a double reflection arrangement similar to that described previously.

According to a first aspect, the invention may then provide a scanning apparatus comprising an optical system 5 having first and second rotatable bodies arranged to rotate at the same speed, in opposite directions, having generally parallel axes of rotation and being inclined to those axes of rotation, the optical systems being arranged to define an optical path for a polarised beam 10 so as to form a linear scan, wherein at least a first one of the bodies is a polariser and the optical system is such that the optical path passes through the polariser, is reflected at the second body, and is reflected by the polariser back to the second body. Preferably the axes 15 are coincident.

There are two general possibilities. In the first possibility, the second body is a mirror, or other reflective disc. In this case the optical path is such that, after the optical path has been reflected by the 20 polariser back to the second body, the second body reflects the beam back through the polariser.

In the second possibility, the second body is a polariser and the optical path is such that once the beam is reflected back to the second body it is transmitted 25 through the second body. This is a transmission system,

with the beam finally passing through the rotatable body, and emerging from the rotatable body in direction in which it was received.

The polariser may be a circular polariser, or may be
5 a linear polariser.

The invention relies upon changes in the orientation of polarisation which affects whether or not the beam passes through, or is reflected by the polariser.

Reflection is one possible way of altering the
10 orientation of polarisation. However, it may be necessary to include in the optical system quarter wave plates or Faraday rotators to alter the orientation of polarisation. This is particularly the case when linear polarisers are used.

15 For example the first body may be a linear polariser, and two rotatable quarter wave plates may be located on either side of the polariser. The quarter wave plates rotate about the same axis as the linear polariser, at the same speed and in the same direction as
20 the linear polariser.

In an alternative, a rotatable quarter wave plate is located on one side of the linear polariser, being rotatable about the same axis as the polariser, at the same speed and in the same direction, and a Faraday

rotator is located on the other side of the polariser.

The Faraday rotator may be fixed or rotatable.

The quarter wave plate(s) and linear polariser are preferably connected to form a rotating unit.

5 The apparatus may have a fixed quarter wave plate to convert linear polarised radiation into circular polarised radiation before it is received by the first body.

Preferably angle of inclination of the first body is
10 twice the angle of inclination of the second body.

Linear scans may also be achieved by using a rotatable reflector and an optical wedge, wherein the wedge includes refractive materials. The wedge and the reflector are arranged so that their conical scan
15 patterns are the same, but in opposite directions, to produce a linear scan pattern. To achieve this, the wedge and the reflector are arranged to counter-rotate about generally parallel axes, and the reflector is inclined to its axis of rotation, as are the faces of the
20 wedge.

With such an arrangement, a beam passes through the wedge, is reflected by the reflector and passes back through the wedge.

Preferably, the axes of rotation of the wedge and
25 the reflector are coincident, and the median plane of the

wedge is preferably generally perpendicular to the axis of rotation.

The wedge may be wholly of refractive material, such as silica, but preferably has refractive plates supported 5 on a refractive core. Refractive material, such as sulphur, may be sandwiched between the plates and the core.

Brief Description of the Drawings

Embodiments of the invention will now be described 10 in detail, by way of example only, and with reference to the following drawings, in which;

Fig. 1 shows an apparatus according to a first embodiment of the invention;

Fig. 2 shows in detail a rotating unit according to 15 an embodiment of the invention;

Fig. 3 shows the path of the beam through the apparatus shown in Fig. 1 and Fig. 2;

Fig. 4 shows an apparatus according to a further embodiment of the invention;

20 Fig. 5 shows an apparatus according to an embodiment of the invention arranged in transmission.

Fig. 6 shows an apparatus according to a further embodiment of the invention;

Fig. 7 shows the wedge of Fig. 6 in detail.

Detailed Description

Referring first to Fig. 1 a rotating mirror 1 is inclined at around 11° and a rotating unit 3, (shown in more detail in Fig. 2) which includes a linear polariser 5 inclined at an angle of around 22°. A fixed quarter wave plate 5 is located in front of the rotating unit 3 to convert a linearly polarised beam to a circularly polarised beam.

Fig. 2 shows the rotating unit 3 in detail. This 10 comprises an inclined linear polariser 10 positioned between two quarter wave plates 13 and 15. The quarter wave plates in this embodiment have fast axes of +45°, though other directions are possible.

A linearly polarised beam is converted by the fixed 15 quarter wave plate 5 to a right circularly polarised beam. In this embodiment, the incident beam is horizontally polarised and the fixed quarter wave plate 5, which has a fast axis at +45° produces right-handed circularly polarised beam. Though other directions are possible, 20 for example, left circularly polarised beam may alternatively be used).

Referring to Fig.3, the right circularly polarised beam passes through the first quarter wave plate 13 of rotating unit 3 which converts the beam to linear 25 polarised. The beam then passes through the polariser 10

and through the second quarter wave plate 15 of the rotating unit, where it is converted to circular polarised light. The beam then reaches the rotating mirror 1, which rotates in the opposite direction from 5 rotating unit 3 but at the same speed, and the beam is reflected from the counter-rotating mirror 1.

The beam then passes back to the rotating unit 3 where it passes through the quarter wave plate 15. This time the light is reflected at the inclined polariser 10, 10 because the plane of polarisation has been rotated through 90° when reflected at the rotating mirror 1 and transmitted by the quarter wave plate 15. The beam then passes to the counter rotating mirror 1 where it is reflected again, the handedness of the circularly 15 polarised radiation undergoing a further change, and passes back through the rotating unit 3, this time passing through the linear polariser 10.

In isolation, the rotating unit 3 and the counter rotating mirror 1 produce conical scans, but in this 20 tandem arrangement, with the rotations at the same speed and in opposite directions. Parts of the conical scans are effectively cancelled out to produce a linear scan. This cancellation is virtually complete if the inclination of the inclined polariser 10 is twice that of 25 the counter-rotating mirror 1.

Fig. 4 shows an alternative embodiment in which the rotating unit 20 consists of a quarter wave 23 plate and a linear polariser 21. The apparatus also has a Faraday rotator 25, which rotates the plane of polarization by 5 45°.

In the embodiment shown in Fig.4, the fixed quarter wave plate 5 converts a linearly polarised beam in to a circularly polarised beam. This circularly polarised beam is received by the rotating unit 20 and is converted 10 into a linear beam by the quarter wave plate 23. The beam then passes through the linear polariser 21 and is then received by the Faraday rotator 25 which rotates the plane of the polarisation of the incident beam by 45°. This beam is then incident at the rotating mirror 1 where 15 it is reflected.

The beam passes back through the Faraday rotator 25 where it undergoes a further rotation of 45° in its plane of polarisation.

The beam is now polarised at right angles to the 20 transmission axis of the inclined polariser 21 of the rotation unit 3. The polariser 21 therefore reflects the incident beam in a conical scan pattern. This reflected beam now passes through the Faraday rotator 25 again and the plane of polarisation is rotated through 45°. The 25 beam is then reflected at the mirror 1, and passes

10

through the Faraday rotator, the plane of polarisation being rotated through 45° so that the beam is then able to pass through the inclined polariser 21 and then through the quarter wave plate 23 of the rotating unit
5 20.

In this way, there are two reflections at the rotating mirror 1 and one at the inclined polariser 21, which is positioned at twice the angle of the rotating mirror 1.

10 It is also possible for two rotating units similar to that described in Fig. 1 to be used in series. This arrangement is shown in Fig. 5. The second unit 30 rotates about its axis with the same speed, but in the opposite direction from the first unit 40, and has a
15 Faraday rotator between the quarter wave plate and the polariser. In this embodiment, it is not necessary to have a rotating mirror, because the polariser in the second rotating unit 40 can act as a mirror. The beam passes through the first rotating unit 30 as described
20 for the first embodiment. The beam then passes to the second rotating unit 40 and is reflected from the inclined polariser of the second unit.

The reflection at the inclined polariser of the second unit rotates the polarisation of the beam through
25 90°, so that when the beam passes back to the first

polarising unit, it is reflected by the inclined polariser (and the polarisation is rotated through 90°). This time when the beam reaches the second rotating unit 40 it passes through the inclined polariser and via a 5 second quarter wave plate 5a which is fixed.

In an alternative embodiment shown in Fig. 6, the rotating unit is a rotating wedge 41 which rotates in the opposite direction from, and at the same speed as, the rotating mirror 1. The rotating wedge 1 is mounted on a 10 drive shaft 42, and a gear box 43 and a motor 44 are used to control the speed and direction. The rotation is further balanced by balance weights 45a and 45b.

Fig. 7 shows the wedge of this embodiment in more detail. The wedge 41 has a sulphur layer 46 sandwiched 15 between two silica plates 47a and 47b, which are coated with anti-reflective PTFE layers 49a and 49b.

At microwave frequencies sulphur has a refractive index of 1.89 which is close to that of silica (1.94).

The silica plates are angled to produce a wedge 20 which will deviate a beam through an angle θ given by:

$$\theta = 2 \operatorname{Sin} (n \operatorname{Sin} \alpha/2) - \alpha$$

at the condition of the minimum deviation, where α is the apex angle of the wedge. For small deviations, this approximates to:

12

$$\theta = (n-1) \alpha$$

where n is the refractive index of the wedge.

- The anti-reflective layer should have a refractive index which is the square root of the refractive index of
- 5 the silica and have an optical thickness of $\lambda/4$ where λ is the wavelength of the radiation. PTFE is therefore an appropriate material for the anti-reflective layer, as it has a refractive index of 1.44 which approximates to the square root of the refractive index of silica (1.89).
- 10 Its thickness should be 1.39 mm for radiation having a wavelength of 8mm (i.e. 35GHz). Alternative materials and thicknesses can be selected by the person skilled in the art. For example, it may be possible to achieve a suitably refractive wedge using a body of silica
- 15 material, thus omitting the sulphur.

A beam incident on the arrangement of Figs. 6 and 7 passes twice through the wedge 46 as it is reflected by the rotating mirror 1.

CLAIMS:

1. A scanning apparatus comprising an optical system having first and second rotatable bodies arranged to rotate at the same speed, in opposite directions, having generally parallel axes of rotation and being inclined to those axes of rotation, the optical system being arranged to define an optical path for a polarised beam so as to form a linear scan, wherein at least a first one of the bodies is a polariser and the optical system is arranged such that the optical path passes through the polariser, is reflected at the second body back to the polariser, and is reflected by the polariser back to the second body.
2. A scanning apparatus according to claim 1 wherein the axes of rotation of the first and second rotatable bodies are coincident.
3. A scanning apparatus according to claim 1 or claim 2 wherein the second rotatable body is a reflective member and the optical path is arranged such that once the polarised beam is reflected back from the polariser to the second body, the second body reflects the beam back to the polariser and the beam passes through the polariser.
4. A scanning apparatus according to claim 1 or claim 2 wherein the second rotatable body is a polariser and the optical path is arranged such that once the polarised

beam is reflected back to the second body it is transmitted through the second body.

5. A scanning apparatus according to any one of the above claims wherein the angle of inclination of the
5 first body is twice the angle of inclination of the second body.

6. A scanning apparatus according to any one of the above claims wherein the first body is a linear polariser.

10 7. A scanning apparatus according to claim 6 wherein first and second quarter wave plates are provided, one on each side of the first body, and wherein the apparatus has means for rotating the first and second quarter wave plates about the same axis as the first body, at the same
15 speed and in the same direction.

8. A scanning apparatus according to claim 7 wherein the second body is a linear polariser, wherein there are third and fourth quarter wave plates, one on each side of the second body, the third and fourth quarter wave plates
20 being arranged to rotate about the same axis as the second body, at the same speed and in the same direction as the second body, and wherein a Faraday rotator is located between the second body and the third quarter wave plate which is located on the first body side of the
25 second body.

9. A scanning apparatus according to claim 6 wherein a quarter wave plate is located on one side of the first body and is arranged to rotate about the same axis as the first body, at the same speed and in the same direction as the first body, and a Faraday rotator is located on the other side of the first body.
10. A scanning apparatus according to claim 7 or claim 8 wherein the quarter wave plate(s) and the first body are connected to form a rotating unit.
- 10 11. A scanning apparatus according to any one of the above claims wherein the apparatus further comprises a fixed quarter wave plate for converting linear polarised radiation into circular polarised radiation before it is received by the first body.
- 15 12. A scanning apparatus having a rotatable reflector and a rotatable optical wedge including refractive materials, wherein the wedge and the reflector are arranged to counter-rotate about generally parallel axes, the reflector and the two faces of the wedge being inclined to their respective axes of rotation, such that in use a beam passes through the wedge, is reflected by the reflector and passes back through the wedge to provide a linear scan.
- 20 13. A scanning apparatus according to claim 11 wherein the axes of rotation of the wedge and the reflector are coincident.

14. A scanning apparatus according to claim 11 or claim 12 wherein the median plane of the wedge is generally perpendicular to the axis of the wedge's rotation.

15. A scanning apparatus according to any one of claims 5 11-13 wherein the wedge comprises refractive plates supported on a refractive core.

16. A method of producing a linear scan, comprising the steps of rotating first and second bodies about generally parallel axes of rotation, at the same speed, but in 10 opposite directions to each other, the first body being a polariser and both the first and second bodies being inclined to their respective axes of rotation, and directing a polarised beam through the first body, so that it is reflected at the second body back to the first 15 body, and is reflected by the first body back to the second body.

17. A method according to claim 16 wherein the second body is a reflective member and wherein after the polarised beam is reflected back from the first body to 20 the second body, the second body reflects the beam back to the first body and the beam passes through the first body.

18. A method according to claim 16 wherein the second body is a polariser and wherein after the polarised beam 25 is reflected back from the first body to the second body it is transmitted through the second body.

19. A method of producing a linear scan including the steps of rotating a reflector and an optical wedge in opposite directions to each other, but around generally parallel axes of rotation, the reflector and the two 5 faces of the optical wedge being inclined to the reflector's axis of rotation and the wedge's respective axis of rotation respectively, and directing a beam so that it passes through the optical wedge, is reflected by the reflector back to the optical wedge and passes 10 through the optical wedge to provide a linear scan.

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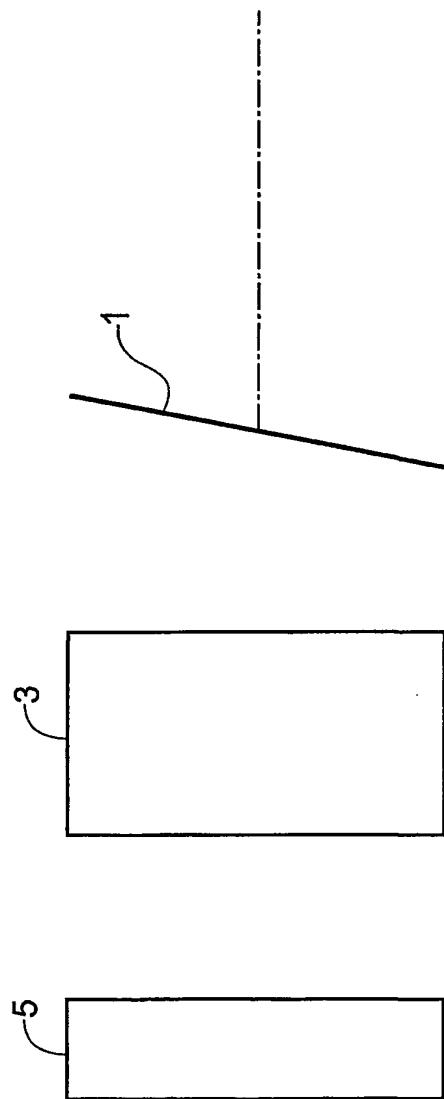


Fig. 1

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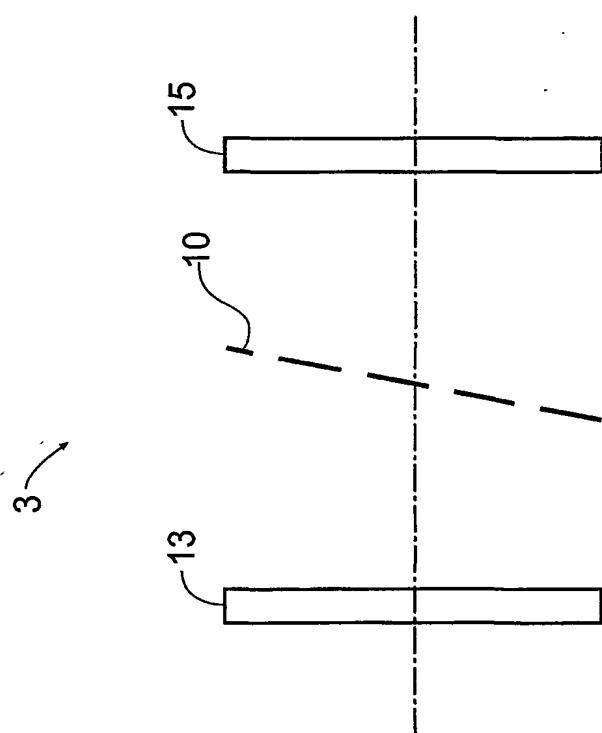


Fig. 2

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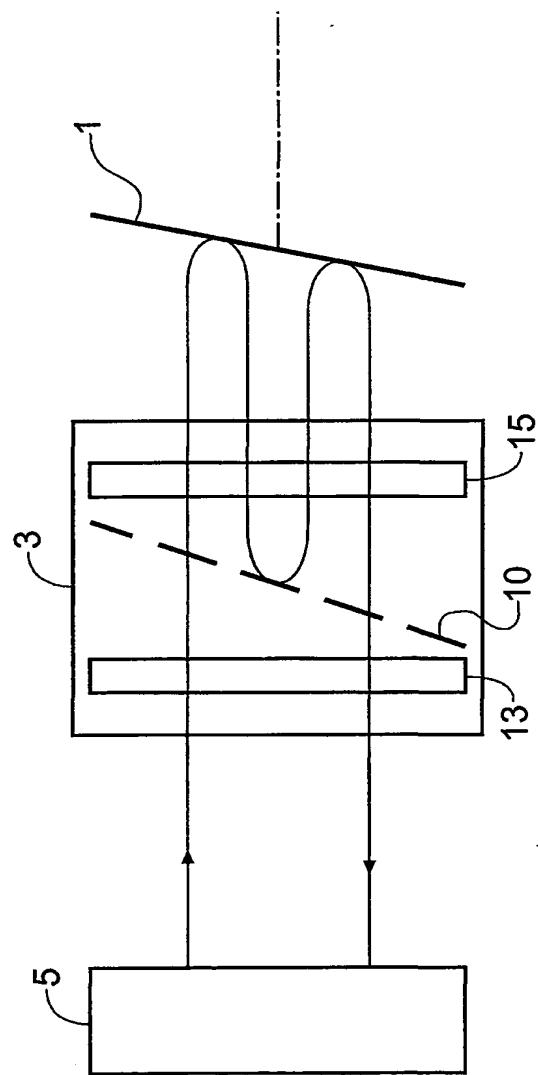


Fig. 3

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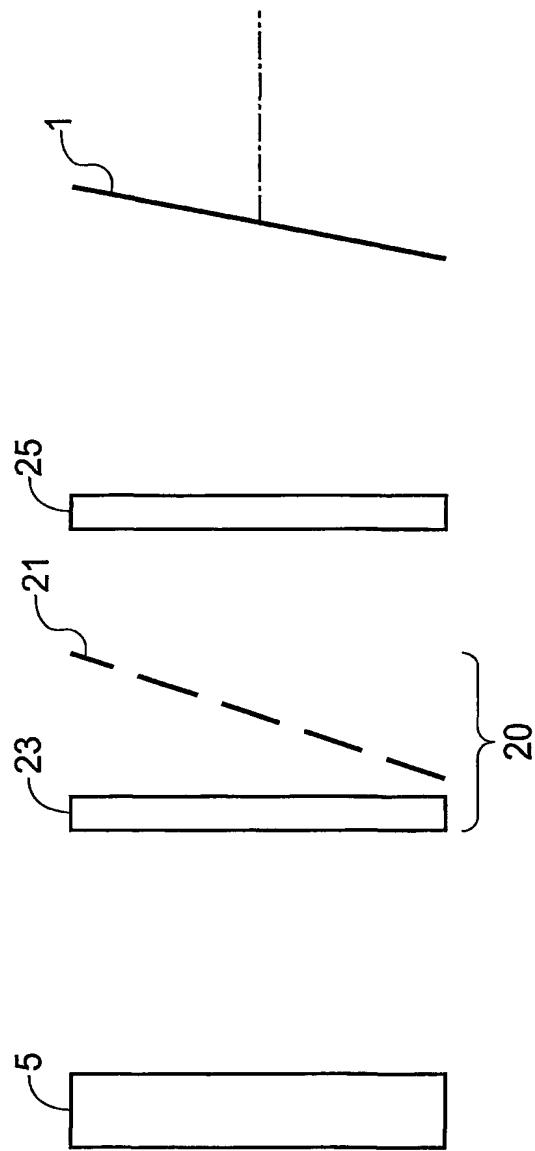


Fig. 4

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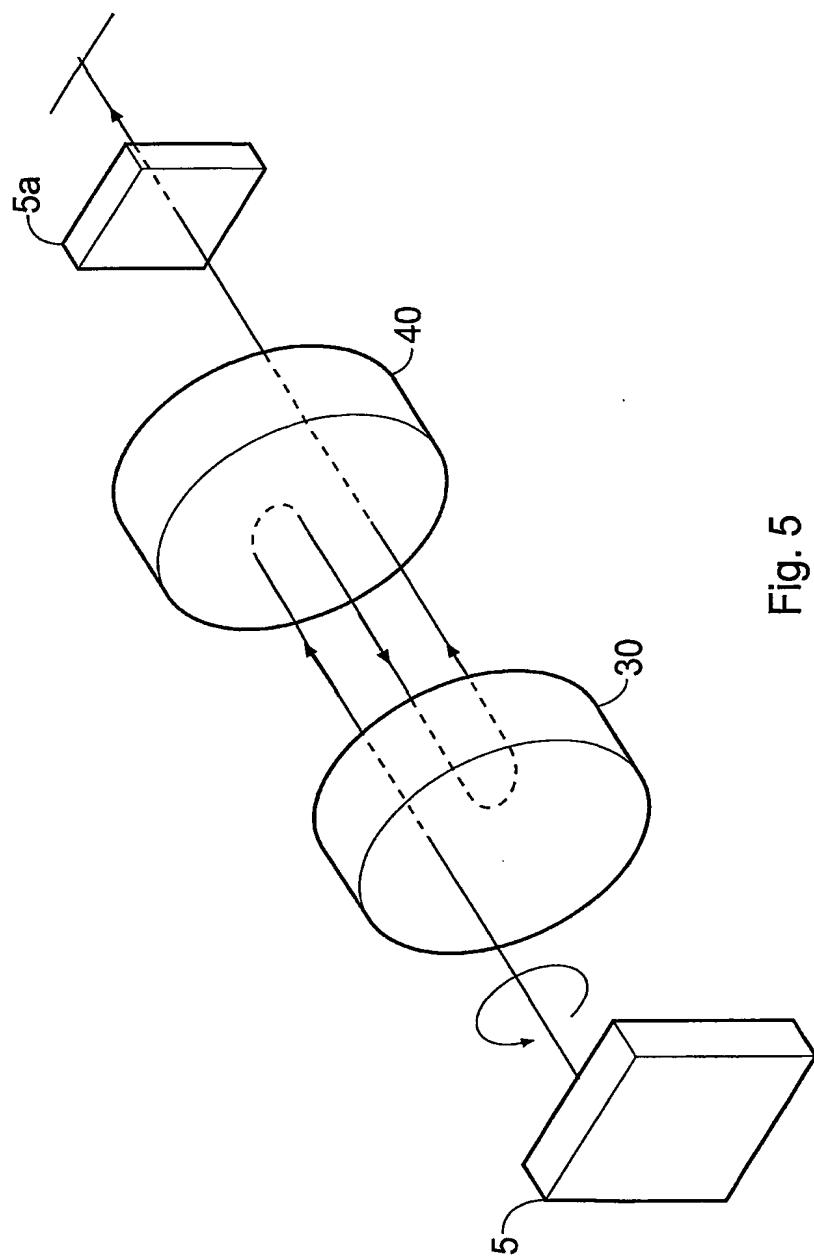


Fig. 5

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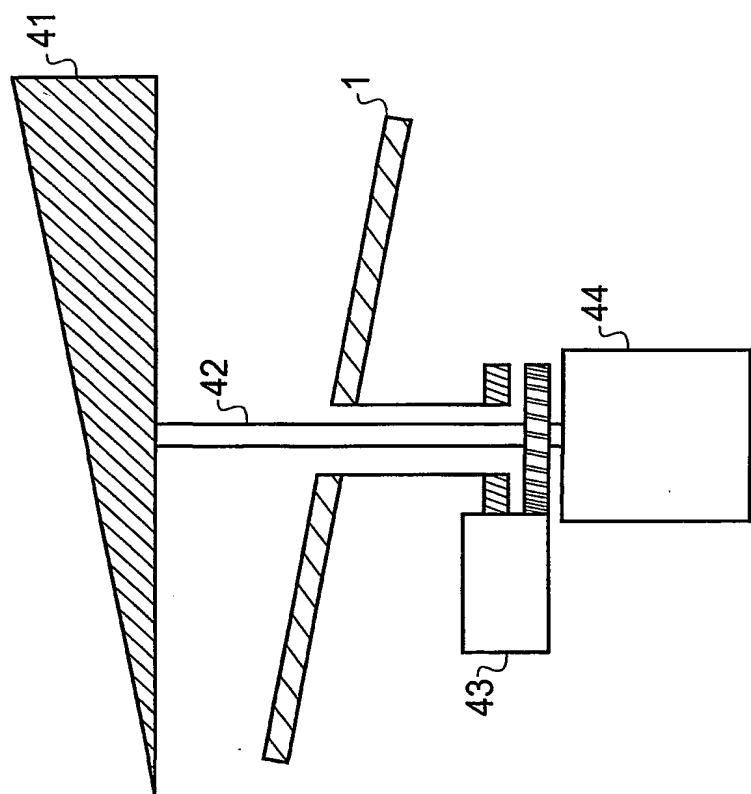


Fig. 6

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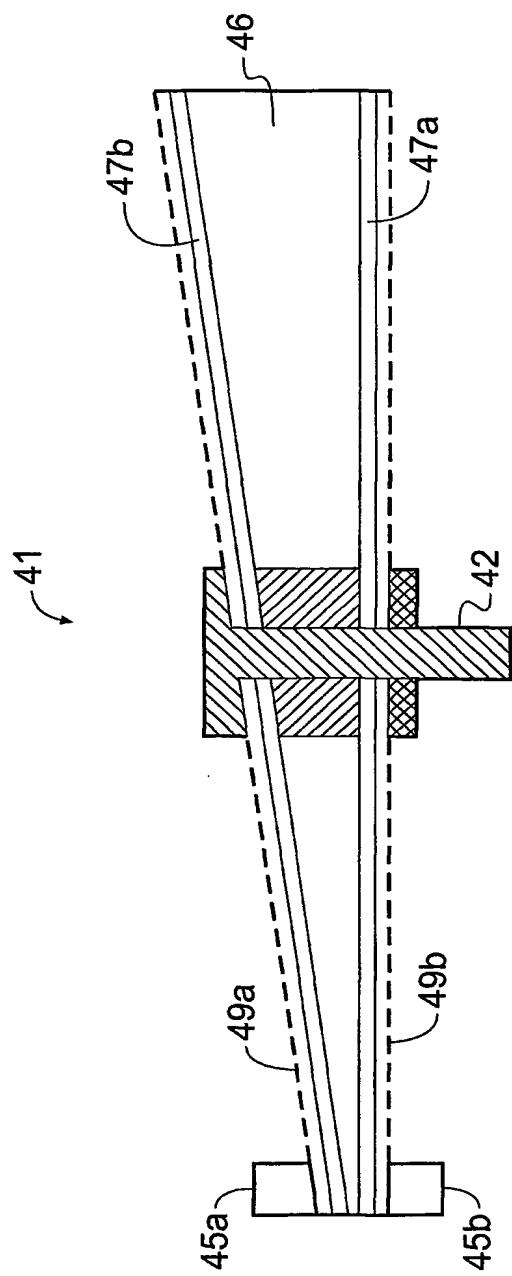


Fig. 7

INTERNATIONAL SEARCH REPORT

Patent Application No
PCT/GB 02/03349

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B26/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|----------|---|-----------------------|
| A | LETTINGTON A H ET AL: "Compact mechanically scanned antennas for real-time passive-millimetre-wave imaging" IEE PROCEEDINGS H. MICROWAVES, ANTENNAS & PROPAGATION, INSTITUTION OF ELECTRICAL ENGINEERS. STEVENAGE, GB, vol. 147, no. 5, 10 October 2000 (2000-10-10), pages 339-342, XP006014302 ISSN: 0950-107X the whole document | 1-19 |
| A | EP 0 633 541 A (OPTICON SENSORS EUROPE) 11 January 1995 (1995-01-11) the whole document | 1-19 -/- |

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Patent family members are listed in annex.

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Date of the actual completion of the International search

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| C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT | | |
|--|---|-----------------------|
| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
| A | US 3 881 802 A (HELAVA UUNO V) 6 May 1975 (1975-05-06) the whole document ----- | 1-19 |
| A | US 4 168 126 A (ALTMAN NORMAN G ET AL) 18 September 1979 (1979-09-18) the whole document ----- | 1-19 |

INTERNATIONAL SEARCH REPORT
Information on patent family members

International Application No
PCT/GB 02/03349

| Patent document cited in search report | Publication date | | Patent family member(s) | Publication date |
|--|------------------|-------|-------------------------|--------------------------|
| EP 0633541 | A 11-01-1995 | EP US | 0633541 A1 5526167 A | 11-01-1995 11-06-1996 |
| US 3881802 | A 06-05-1975 | | NONE | |
| US 4168126 | A 18-09-1979 | | NONE | |